REMARKS

Applicant respectfully requests entry of this Amendment and reconsideration of this application, as amended.

Claims 1 to 15, 17, 19 to 21, and 27 to 30 are currently pending in this application. Claims 22 to 26 have been withdrawn from consideration and canceled. Claims 16 and 18 have been canceled and rewritten in independent form as new claims 29 and 30. Claims 1, 17, 19 to 21, and 27 have been amended and new claim 28 has been added. Support for new claim 28 can be found in original claim 27. Support for the amendments to claims 1 and 27 can be found in paragraphs [0005] to [0007] of the specification, as originally filed. The amendments to claims 19 to 21 reflect a change in dependency.

The Examiner is thanked for the courteous interview extended on November 21, 2005, at which time the Examiner agreed to withdraw the rejection of claims 16 to 21. The Examiner also agreed to reconsider claims drawn to "hydrocarbonaceous material selected from the group consisting of oil shale, tar sand, coal, oil sand, bitumen and/or kerogen."

Applicant notes that an erroneous attorney, not associated with customer number 25570, appears under the attorney heading in Public Pair (copy attached) of the USPTO records. Correction is requested.

Restriction Requirement

Applicants confirm election without traverse of claims 1-21 and 27. Accordingly, claims 22 to 26 have now been canceled in order to advance prosecution.

Information Disclosure Statement

A copy of the Duncan article entitled "Enhanced recovery engineering…including well design, completion and production practices," is being filed concurrently herewith.

Rejection Under 35 U.S.C. 102

Claims 1-15, 17-21, and 27 have been rejected under 35 U.S.C. 102(b) as being anticipated by U.S. Publication No. 2002/0047009 (now U.S. Patent No. 6,657,173) to Flugstad et al. (Flugstad), which teaches heating a food product by maintaining the food product in an AC electrical field generated by an RF signal.

The present invention is related to heating a hydrocarbon bearing formation using a variable frequency automated capacitive radio frequency (RF) dielectric heating in situ process. Separation of desired hydrocarbons from less sought after constituents can occur in a carrier medium subterranean reservoir. The instant specification is replete with references to oil shale and tar sand containing hydrocarbonaceous material. Applicant discloses in paragraph [0150] that "[t]he electrical heating techniques disclosed below are applicable to various types of hydrocarbon-containing formations, such as oil shale, tar sands, coal, heavy oil, partially depleted petroleum reservoirs, etc."

Independent claim 1 (currently amended) recites "[a] method for heating a medium, said medium comprising hydrocarbonaceous material selected from the group consisting of oil shale, tar sand, oil sand, coal, bitumen, and/ or kerogen." Independent claim 27 (currently amended) recites "[a] method for heating specific chemical compositions that reside in hydrocarbonaceous material selected from the group consisting of oil shale, tar sand, oil sand, coal, bitumen, and/ or kerogen. Flugstad, on the other hand, clearly teaches heating a food product. Flugstad specifically discloses in paragraph [0046] "food products which are defined herein to include conventional foods, agricultural products from which foods are derived (e.g., seeds for sprouts), as well as other edible substances (e.g., edible films used to package seeds)." Flugstad further discloses the food product to be heated by a capacitive RF dielectric heating system is contained in packaging material (paragraph [0155]).

Additionally, Flugstad discloses in paragraph [0007] that "[c]apacitive radio

frequency (RF) dielectric heating is used in several industries. They include the drying of various wood and sawdust products in the timber industry, preheating and final drying of paper, drying of textiles, drying of glass fibers and spools, drying water-based glues in the paper-cardboard industry, drying pharmaceutical products, welding plastics, sealing, preheating plastics prior to forming, firing foundry cores in casting, polymerization of fiber panels, gluing of woods such as laminated plywood, printing and marking in the textile, leatherware and shoe industries, melting honey, heating rubber prior to vulcanization, welding glass formed sections, bonding multi-layer glass products, drying of powders, drying leathers and hides, curing of epoxy, curing of plastisol, curing of brake linings, impregnating resins, thermosetting adhesives, curing hardboard and particle board, and many other applications." None of the industries have any relationship to the petroleum industry.

Heating of the Flugstad food product is clearly not anticipatory of Applicant's claimed invention which is directed to heating hydrocarbonaceous material. To support an anticipation rejection based on inherency, the Examiner must establish that the inherent feature necessarily flows from the teachings of the prior art, Flugstad. The inherency of Applicant's claimed hydrocarbonaceous material from the Flugstad food product is not a necessary conclusion. Claims are not read in a vacuum. The claims must be analyzed in light of the entire disclosure.

Applicant notes that claim 16 (canceled) and rewritten as independent claim 29 (new), which recites a subterranean environment, is correctly excluded from the 35 U.S.C. 102 rejection based on Flugstad. Yet, instant claims 18 (canceled) and rewritten as independent claim 30, and 19 to 21 (currently amended), which recite a subterranean reservoir, have been rejected under 35 U.S.C. 102. Correction and/or clarification is requested.

In view of the above, withdrawal of this rejection under 35 U.S.C. 102 (b) is respectfully requested.

Rejection Under 35 U.S.C. 103

Claim 16 has been rejected under 35 U.S.C. 103(a) as obvious over U.S. Publication No. 2002/0047009 (now U.S. Patent No. 6,657,173 to Flugstad et al. (Flugstad) in view of U.S. Patent No. 4,645,004 to Bridges et al. (Bridges). Bridges teaches an electro-osmotic method for the production of hydrocarbon utilizing in-situ heating of earth formations.

Bridges fails to overcome the deficiencies of the primary reference, Flugstad. There is no disclosure anywhere in Bridges as to food products, the crux of the Flugstad reference. It would not have been obvious to one of ordinary skill in the art to substitute the hydrocarbonaceous earth formations of Bridges for the food products of Flugstad, absent hindsight reconstruction. For purposes of evaluating the obviousness of claimed subject matter, the reference relied on must constitute analogous art. Flugstad is certainly non-analogous both to the claimed invention and to Bridges. Claim 16 (canceled) has been rewritten in independent form as claim 29 (new).

It is difficult, if not impossible, to imagine how one skilled in the art in possession of these references could conceive of the present invention absent hindsight reconstruction which was prohibited by the Supreme Court in *Diamond Rubber Co. v. Consolidated Rubber Tire Co.*, 220 U.S. 428 435-436 (1911). To find obviousness, "there must be some reason for the combination other than the hindsight gleaned from the invention itself." *Interconnect Planning Corp. v. Feil*, 227 U.S.P.Q. 543, 551 (Fed. Cir. 1985). Stated in another way, "[I]t is impermissible to use the claimed invention as an instruction manual or 'template' to piece together the teachings of the prior art so that the claimed invention is rendered obvious." *In re Fritch* 23 U.S.P.Q.2d 1780, 1784 (Fed. Cir. 1992).

Given the foregoing shortcomings of Flugstad and Bridges, it is respectfully submitted that Flugstad and/or Bridges fail to disclose or suggest the invention of claims 1 to 15, 17, 19 to 21, and 27 to 30. Accordingly, withdrawal of the rejections under 35

U.S.C. 102 (b) and 35 U.S.C. 103(a) is respectfully requested.

In view of the foregoing remarks, it is respectfully submitted that the present claims describe heating a hydrocarbon bearing formation using a variable frequency automated capacitive radio frequency dielectric heating in situ process that meets the requirements of patentability. Applicant therefore respectfully requests that a timely Notice of Allowance be issued in this case.

Any comments or questions concerning the application can be directed to the undersigned at the telephone number given below.

Respectfully submitted,

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10/801,458 In situ processing of hydrocarbon-bearing formations with variable frequency automated capacitive radio frequency dielectric heating

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Close Window

Enhanced recovery engineering . . .

including well design, completion and production practices

Electric heat—Concluding article of 10-part series describes four processes for applying electricity downhole to heat formation or tubulars. Case histories and design considerations illustrate applications

This concluding article, the 10th in a series, follows *World Oil* articles on EOR downhole conditions (September 1994), corrosion (November 1994), tubulars and connections (January 1995), thermal well design (March 1995), completion practices (May 1995), steam process wells (July 1995), chemical process wells (September 1995), gas process wells (November 1995) and combustion processes (January 1996).

Grant Duncan, Petro-canada, Calgary, Alberta

Electric heat as an EOR process offers a number of advantages. Given the right reservoir conditions, heat can be precisely placed in the zone of interest; and conditions that make electric heat viable are often different than would be required for chemical, gas, steam or combustion projects. Electric heat can: 1) remove "skin" caused by near-wellbore paraffin deposition or viscous crude, 2) remove hydrates or paraffin deposits in tubulars, and 3) be applied to viscous crudes that are immobile under normal reservoir conditions. Disadvantages are largely economic due to requirements such as: more expensive wellbores, higher operating costs and closer well spacing.

Electric heat processes discussed in this concluding article include inter-well electromagnetic (EM) heating, single-well EM heating, EM tubing heating, and radio-frequency (RF) heating. Design considerations such as frequency effects, inductive power loss and equipment isolation/insulation are given. Four case histories are discussed, along with several operating tips on efficiency, monitoring and safety.

ELECTRIC HEAT PROCESSES

By properly choosing spacing and frequency, the path taken by electric currents can be controlled to a great extent. Reservoir heterogeneities that adversely affect injected fluids have much less effect on electric currents.

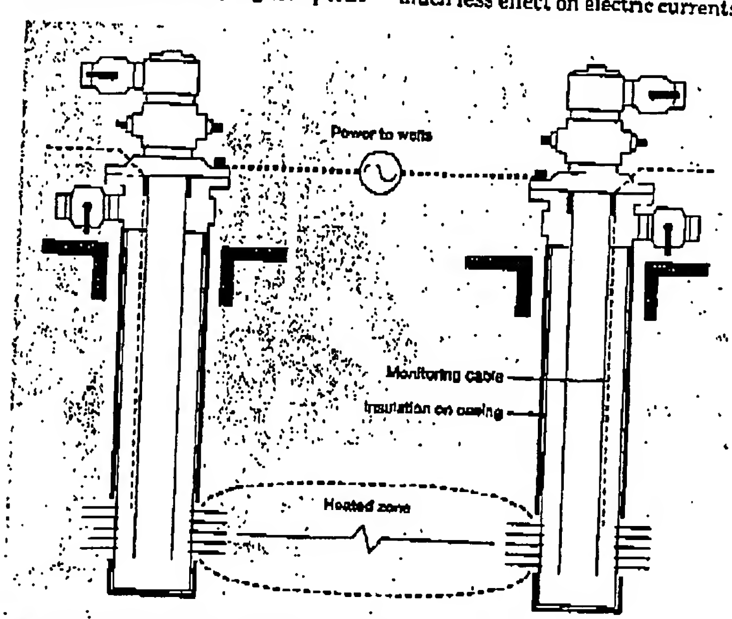

Fig. 39. Inter-well electric heating heats only the target formation. Externally insulated casing extends above ground level. When all metal components in the wellbore are electrically "hot," inductive power loss is minimized.

With inter-well heating, it may even be possible to place electrodes in different zones.[105] Oil displacement by EM heating alone is inferior to steam due to the absence of a sweep mechanism. Thus, EM effectiveness can be enhanced by combining it with a displacement mechanism such as steam or gas injection.[107]

Inter-well EM heating relies on current flow between electrode wells, and is used to preferentially heat portions of the reservoir some distance from the wellbores, Fig. 39. Much more heat can be placed in the formation with inter-well EM than with single electrodes.

Single-well EM heating sends electric power down a single wellbore and completes the circuit through overlying formations to "ground" wells, Fig. 40, or to the wellbore casing, Fig. 41. Single-well EM heats near-wellbore regions and would be used to reduce wellbore skin caused by paraffin deposition or the visco-skin effect.

EM tubing heating is a variation on single-well EM, Fig. 42. Electric current flows down tubing to a pre-determined point in the wellbore where tubing is grounded to casing. The tubing is warmed primarily by resistance heating, which aids in removing wellbore paraffin deposits or hydrates.

Radio-frequency (RF) heating is another single-well heating process. An antenna or excitor is placed across the zone of interest and powered by a high-frequency source. RF only heats the near-wellbore region, and could be considered where: 1) there is little initial water in the formation, or 2) it is desirable to heat near-wellbore formations to high tem

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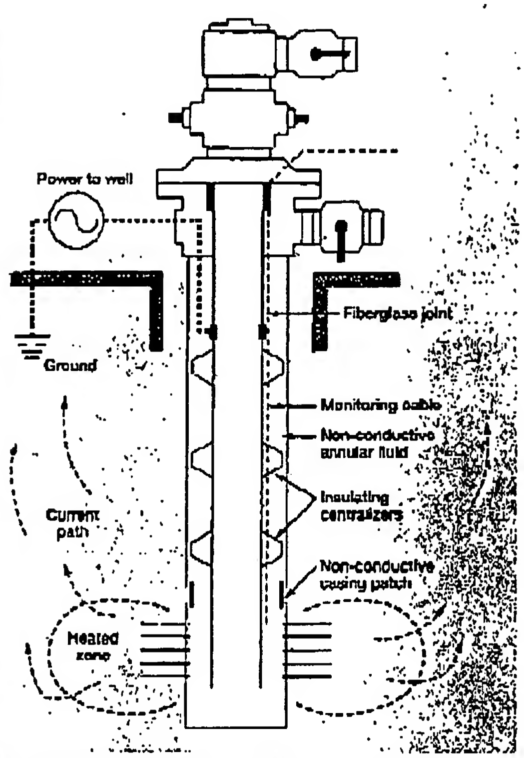

Fig. 40. Single-well heating with circuit completed to surface. Power conducting tubular must be electrically isolated from neutral casing.

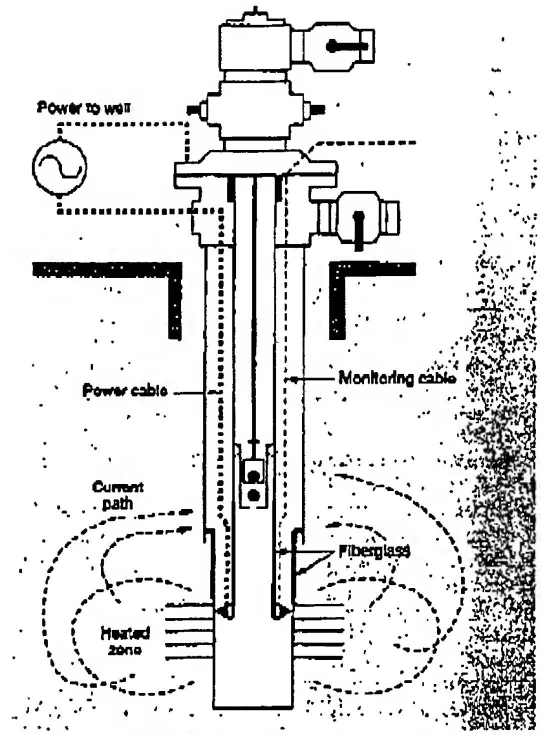

Fig. 41. Single-well heating with circuit completed to casing. Power is transmitted to electrode area by insulated power cable. Fiberglass liner separates electrode from casing.

DESIGN CONSIDERATIONS

Three important electric heating considerations that must be incorporated into well/facility designs are discussed here. These are: 1) frequency effects, 2) inductive power loss, and 3) equipment isolation by various insulating mechanisms.

Frequency effects. Electric resistance heating (ERH) occurs at frequencies less than 300 kHz, with the formation acting as the heating element. Higher frequencies, referred to herein as radio-frequency (RF) heating, can range from radio frequencies (kHz) to microwave frequencies (MHz). Low frequencies result in low intensities and greater depth of penetration, whereas high frequencies are more rapidly attenuated, leading to near-wellbore heating.[107, 108]

Very low frequencies, down to 2 Hz, or direct current heating, have been considered. Power loss is decreased and depth of penetration increases at very low frequency, but corrosion rates are expected to increase.[109] Most EM projects would utilize commercially available frequencies in the range of 50–60 Hz. Alternatively, variable frequency controllers, as used for electric submersible pumps (ESPs), are available with a frequency range of 30–90 Hz.

Inductive power loss. This occurs when steel components in wellbores are electrically isolated from power transmitting components. Casing that is not part of the circuit is the most likely cause of inductive power loss in electrode wells. The greater the mass of isolated steel surrounding power transmitting tubulars, the greater will be the inductive loss. From a power conservation perspective, electrically "hot" casing reduces inductive loss and is the most efficient way to transmit power, Fig. 39. Isolating casing from a power transmitting tubular will increase inductive power loss, Fig. 40.

Equipment isolation. Electric power can be transmitted to the zone of interest by casing, tubing or power cables. Casing used as a power conductor must be isolated from all formations but the zone of interest, requiring new purpose-built electrode wells. If fiberglass (FRP) casing is used as exterior insulation, consider using lightweight cement to reduce external (collapse) pressure, allowing use of lighter grades of FRP casing. Alternatively, steel casing can be coated with insulating materials such as high-density polyethylene or enamel. It can be challenging to get coated casing to bottom without damaging coatings, thus causing electric shorts to overlying formations.

Choose pipe dopes that contain metal particles, thereby improving electric contact across casing couplings. If steel casing and wellheads are to be part of the circuit, insulation on casing should extend about 3 ft (~ 1 m) above ground level to prevent a short to ground, Figs. 39 and 43; and this section of insulation must be kept clean. Although a minor consideration in

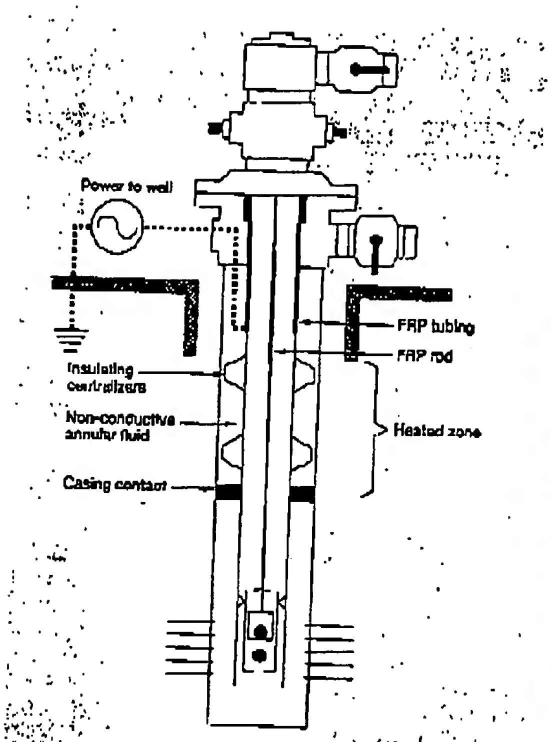

Fig. 42. Electric tubing heating. Upper portion of tubing is heated to remove paraffin deposits or hydrates.

Fig. 43. PCEJ electrode wellhead. These multi-purpose wells transmitted significant electric power to the formation, permitted steam injection, produced both hot and cold bitumen, and monitored downhole conditions.

electrode design, some cements offer improved electric resistance.

Existing wells can be converted to electrodes by creating downhole insulating sections in casing above the zone to be heated, Fig. 40. A "window," milled in the casing, would be covered with a non-conducting liner. Power-transmitting tubulars must be separated from casing by non-conducting centralizers; the annular space must be filled with non-conducting fluid; and contamination of annular fluid with electrolytes must be prevented. Elastomer, bakelite or ceramic non-conductive centralizers will separate tubing from casing.

An electrically "hot" wellhead can be separated from the casing head by non-conductive flange gaskets and bolt isolation assemblies commonly used for corrosion control, but this equipment must be kept clean to prevent shorts due to higher voltages used in electric heating. When wellhead and casing are not part of the circuit, fiberglass tubing and sucker rods in the upper portion of the wellbore can effectively isolate electrically "hot" tubing from the wellhead, Fig. 42.

Power transmission by cable is similar to that for downhole ESP installations, with cable size determining how much power can be transmitted.

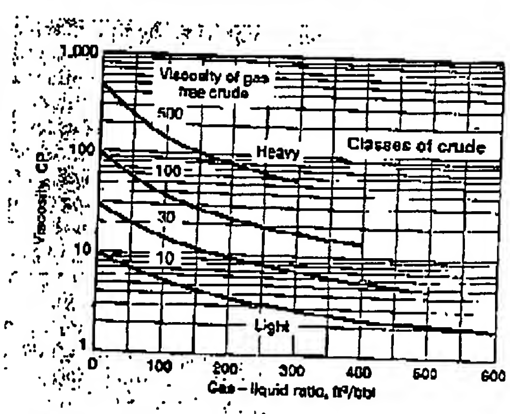

Fig. 44. Visco-skin effect, adapted from Beal.[114] As crude approaches wellbore, pressure drop promotes gas breakout. Viscosity of crude increases in near-wellbore region, resulting in apparent skin and reduced productivity.

Again, it is necessary to isolate casing from the zone to be heated to encourage electricity to enter the formation rather than short circuit to the casing. It is also necessary to isolate the armored exterior of the power cable to prevent short circuit to uphole tubulars.

PROCESS SPECIFIC FACTORS

Some specific design/installation/operation considerations for each of the four electric heating processes noted above are discussed. Example problems/solutions from four field/test applica-

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tions in Alberta, Canada; Schoonebeek field, the Netherlands; West Texas: and Oklahoma are presented.

Inter-well EM heating. This process applies heat directly to, and only to, the target formation. The formation can be pre-heated along a predetermined path, thus providing a preferred course for drive fluids such as steam or gas that will subsequently be injected. More heat can be placed deeper in the formation with multiple wells than with single-well EM heating, and the process is self directing. As connate waters flash into steam, current is diverted from the highly resistive vapor phase toward lower-resistivity connate waters which have yet to be vaporized. Residual water salinity determines reservoir fluid conductivity and influences how far the electricity can penetrate.[107]

Inter-well EM heating of oilsands was successfully demonstrated at the PCEJ pilot in N.E. Alberta. The PCEJ consortium comprised Petro-Canada (as operator), Esso Resources, Canada Cities Service and Japan Canada Oil Sands. The project involved two stages—electric preheat and steam drive.[110] Pilot objectives were to demonstrate inter-well EM heating, establish inter-well communication and compare efficiency of pre-heated and non-heated patterns.[111] The pilot contained four directionally drilled electrode wells—1,475-ft (450-m) deep, on 100-ft (30-m) spacing, with 50-ft (15-m) long electrodes.

PCEJ electrode wells, Fig. 43, had to serve many purposes: 1) efficiently conduct electric power to the target formation, 2) permit steam injection while maintaining well integrity, 3) produce both hot and cold bitumen, and 4) monitor downhole conditions. Wells were designed to apply significant power (up to 4,200 V/1,000 A) to the formation at minimal power loss. Eight observation wells, capable of monitoring temperature, pressure and voltage, were located in the pilot area. Voltage measurements in electrode and observation wells indicated that PCEJ electrode wells were 95% efficient in transmitting electricity to the target zone.[110]

Electric heating operations commenced in April 1981. Within five months, reservoir temperature at the quarter point between electrodes had increased from an initial 50°F to 172°F (10°C to 78°C), while midpoint temperature reached 100°F (38°C). Temperature logs in observation wells indicated heating was confined to the pay zone, with very little heating above or below the zone of interest.[110]

Despite the high power efficiency of PCEJ electrodes, a circulation system was required to cool wellbores above the zone of interest due to the quantity of power being transmitted. It was also necessary to prevent connate water flashing into steam, which would impede electricity flow in the formation since steam is a poor conductor. Saline water was injected into electrode wells during electric heating to cool the pay zone and provide a conductive fluid to increase effective wellbore radius. Without cooling, the near-wellbore region could reach 343°F (172°C), equivalent to steam temperature at bottomhole pressures.

Electrode wells must be electrically isolated from surface facilities. At the PCEJ pilot, a proprietary isolation-dissipation system allowed injection of conductive fluids while simultaneously applying significant electric power to the electrode wells. Following electric preheat, steam was injected into PCEJ electrode wells, and no wellbore problems were encountered. The pilot demonstrated that hot inter-well communication channels can be developed in a predictable manner using electric currents to selectively heat portions of the reservoir.[106]

Single-well electromagnetic heating. Selective near-wellbore EM heating can improve wellbore inflow by removing wellbore skin caused by paraffin deposition or increasing oil viscosity. Skin refers to a zone of reduced permeability close to the wellbore. Wellbore skin can include effects of partial penetration, crushed zone at perforations, mud damage, turbulence or non-newtonian flow effects, scale, paraffin deposition and changing oil characteristics. The latter two effects can be remedied by near-wellbore electric heating.

Paraffin deposition in near-wellbore regions results from cooling by circulated fluids or adiabatic expansion during production. A demonstration of how paraffin skin can be removed with EM heating occurred in Schoonebeek field, the Netherlands.[112] Paraffin there has a cloud point of ≈105°F (40°C), and a re-melting point of ≈140°F (60°C). Heat was applied to a single-well electrode and production rates increased abruptly as wellbore temperatures approached 140°F. However, increasing wellbore temperature beyond 140°F did not further increase production, which is consistent with the assumption that high apparent skin was caused by wax or paraffin deposits near the wellbore.

Visco-skin refers to an increase in fluid viscosity as it approaches the wellbore.[113] As pressure decreases, gas evolves from the "live" oil and viscosity increases. The greater the viscosity of the fluid in the reservoir, the greater must be the driving force to cause flow. Fig. 44 illustrates variation in reservoir oil viscosity as a function of gas content.[114] Production increases in single-well EM heating demonstrations[107, 115] have been attributed to near-wellbore viscosity reductions in produced crude. Coincidentally, one project reported decreasing watercuts as reservoir temperature increased. This was attributed to improvement in the relative viscosity of oil, compared to water.[115]

Energy flow in many single well, heavy oil electric heat wells is into the reservoir and back to surface "grounds" to complete the circuit, Fig. 40. Well completions can use bare steel casing, Fig. 40, or electrically isolated casing, Fig. 39. Handle insulated casing carefully since damage to the insulation will cause power loss to overlying formations and ineffective power application to the zone of interest.

The Schoonebeek well separated electrode from casing with a fiberglass liner, and used armored, insulated power cable to transmit power to the electrode.[112] In this configuration, low-frequency current flows radially a few meters from the electrode, then bends vertically toward upper casing, in the same well, which acts as the return electrode, Fig. 41.

Electromagnetic tubing heating. EM tubing heating is a variation on single-well EM heating, and is used to remove or prevent paraffin and hydrate buildup in tubulars, Fig. 42. EM tubing heating should be applied when fluids are stationary or moving slowly, otherwise it is difficult to apply enough power to heat both tub-

ing and flowing fluids to an adequate temperature.

In a West Texas CO_2 flood, the process has eliminated production interruptions caused by a combination of downhole paraffins and hydrate buildup, exacerbated by CO_2 cooling.[116] It is reportedly preferable to hot oiling, which resulted in wax plugging of perforations. Uphole electric shorts, caused by deposits of paraffin mixed with FeS which had built up on electric insulators, required that wellbores be cleaned of such deposits on initial installation.[116]

EM tubing heating systems can be operated continuously or intermittently. Pulsed operation, where system power is turned on and off on a regular cycle, is more economical than continuous heating.[117] During power-on cycles, fluid in the tubing is heated to above the wax melting point, thus removing buildup on both rods and tubing.

Radio frequency heating. RF heating is another variation on single-wellbore heating, with energy being supplied to the near-wellbore region by a high-frequency source. At frequencies above 300 Hz, currents are rapidly absorbed and penetrate only limited distances. A goal of both field and lab RF experiments has been to heat oil-bearing sands or shales to temperatures above the vaporization point so that some in-situ cracking would occur.[118] Lab experiments have demonstrated that RF heating can continue even after near-wellbore water has flashed into steam, and may be applicable to formations that contain little initial moisture.

An IITRI field test in Oklahoma used RF to raise formation temperature to 212°F (100°C) from 64°F (18°C) close to the wellbore, and to 91°F (33°C) 15 ft away, thus allowing a viscous 6°-API oil to be produced.[119] The test used a downhole cylindrical antenna-excitor of copper clad steel that was powered by a 40 kW transmitter.[106]

OPERATIONS

Operational concerns include heating efficiency, production, monitoring and safety. It is important to design wells for temperatures and pressures that may be encountered. Downhole conditions in electric heating are similar to those of steam projects because water in the near-wellbore region can be flashed into steam. Precipitates can form when saline connate waters flash and the resulting vapor is driven by expansion away from the wellbore. Accelerated corrosion rates are a concern due to the impressed electric current.

Production of heated 7°-API crude at the PCEJ pilot proved to be somewhat of a challenge due to overburden temperatures of less than 50°F (10°C). The heavy crude cooled as it left the heated zone, and even though sucker rods were going up and down, no fluid was being produced. This problem had been foreseen, however, and hollow sucker rods with downhole diluent injection pumps had been installed (see Article 5, May 1995, for pump details). Injection of a small quantity of diluent remedied gelled-crude situations.

The operator may wish to monitor for temperature, pressure, current and voltage. To measure voltage in an observation well, sensors will need to contact formation fluids. Measurements transmitted by conducting cables may be distorted by induced currents when applying power to wells.

SAFETY

Electric heat processes are non-polluting, and electricity is invisible. However, because of this characteristic, caution is required. Oilfield workers are not accustomed to working around electrically "hot" wellheads and adjacent piping. Electric heat operations require worker education and warning signs, plus barriers, lock-outs and interrupt switches that shut down power should barriers be bypassed.

Electric isolation of "hot" electrode well components from facilities such as inactive pumpjacks and flowlines is required for safety and power loss reasons. One of the safest isolation methods is to physically disconnect electrodes from production facilities. This can be accomplished by removing short sections of piping and, on inactive pumping wells, physically disconnecting pumpjack bridles to ensure that polished rods do not touch horseheads on pumpjacks.

Fluids such as saline waters can be conductive over hundreds of feet, and therefore can carry current across short isolators. Piping that carries these fluids must either be physically separated or capable of dissipating voltage without adversely affecting efficiency.

Series conclusion

This article concludes the 10-part series on production engineering aspects of enhanced oil recovery. I have indeed been fortunate to work on such interesting projects at Petro-Canada. I wish to thank my co-authors, the Petro-Canada library staff, those who assisted in preparing and proofing the papers and others at Petro-Canada who encouraged this writing. I thank *World Oil*, especially Mark Teel and Bob Snyder, for the opportunity to publish these papers in their fine magazine. Finally, I thank my family for their patience and understanding while the series was being written.

Grant Duncan

ACKNOWLEDGMENT

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LITERATURE CITED

106 Chute, F. S., and F. E. Vermeulen, "Present and potential application of electromagnetic heating in in-situ recovery of oil," *AOSTRA Journal of Research*, 1988.

107 Chakma, A., and K. N. Jha, "Heavy oil recovery from thin pay zones by electromagnetic heating," paper SPE 24817, presented at the SPE Annual Technical Conference & Exhibition, Washington, D. C., October 4–7, 1992.

108 Baylor, B. A., J. B. Maggard and R. A. Wattenbarger, "Improved calculation of oil production response to electric resistance heating (ERH)," paper SPE 20842, September 1990.

109 Anon, "AC current heats heavy oil for extra recovery," *World Oil*, May 1970.

110 Towson, D., "The electric preheat recovery process," Unitar II, February 1992.

111 Khosla, A., and D. E. Towson, "Application of computer modelling to the PCEJ electric preheat/steamdrive Athabasca pilot," CIM paper 85-36-31, June 1985.

112 Rice, S. A., A. L. Kok and C. J. Neate, "A test of the electric heating process as a means of stimulating the productivity of an oil well in the Schoonebeek field," paper 92-04, 43rd Annual Petroleum Society of CIM Meeting, February 1992.

113 McGee, B. C. W., "The vicso skin effect in heavy oil reservoirs," M. S. Thesis, University of Calgary, 1989.

114 Beal, A. B., "The viscosity of air, water, natural gas, crude oil and its associated gases at oil field temperatures and pressures," *AIME transactions*, Vol. 165, 1946.

115 Davison, R. J., "Electromagnetic stimulation of Lloydminster heavy oil reservoirs: Field test results," paper 91-31, Petroleum Society of CIM & AOSTRA Technical Conference, 1991.

116 Baud, W., and B. Eastlund, "Electric tubing heater improves well production in CO_2 flood," *Oil and Gas Journal*, April 1994.

117 Eastlund, B. J., et al., "New system stops paraffin buildup," *Petroleum Engineer International*, January 1989.

118 Bridges, J. E., C. C. Sresty and H. Dev, "In situ RF heating for oil sand and heavy oil deposits," Unitar III, July 1985.

119 Bridges, J. E., et al., "Electromagnetic stimulation of heavy oil wells," Unitar III, July 1985.

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